

SAFETY ASSESSMENT MODEL OF COASTAL PASSENGER VESSEL IN THE
PERSPECTIVE OF LIFE JACKET COMPATIBILITY

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To my beloved family, teachers and supporting group in UTM

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ABSTRACT

This research was conducted due to frequent occurrence of passenger vessel accidents related to the use of life jackets, which believed due to incompatibility between life jackets and passenger vessels. To address this problem, the research sets to develop a safety assessment model of coastal passenger vessel (CPV) in the perspective of life jacket's compatibility, which is known as Life Jacket Compatibility Index (LCI) model. The main purpose of LCI model is to evaluate the life jacket's compatibility with CPV. The LCI model was developed based on a combination of variables from four previous safety models. Compatibility was introduced as a new variable in the present model. The development of the LCI model started by mapping the variables from both life jacket model and passenger vessel safety combined model. Variables were selected based on the research criteria and used to develop the Life Jacket Compatibility Index (LCI) model. The LCI model was transformed into LCI Static and LCI Dynamic algorithms that are based on Fault Tree analysis approach. The LCI Static assesses the life jacket's compatibility with CPV which is under the approved plan and number of passengers, while the LCI Dynamic assesses the same compatibility during CPV is in the operational mode. The LCI model's accuracy was verified by using regression method and the results were further validated by case studies and sensitivity analyses. Results from LCI Static showed that the open-deck CPV *Explorer 320* equipped with inherently buoyant life jackets has better compatibility (2.79) than closed-deck CPV *Duta Pangkor 3* and *Bahagia No. 1* (1.79 and 1.84 respectively). The LCI model was used to improve the safety performance of *Bahagia No. 1*. It was found that LCI Dynamic of the vessel can be improved by 3.4% when the number of passengers was reduced from 57 to 55. In conclusion, the newly developed LCI model is significant to assess and improve the safety of CPV.

ABSTRAK

Kajian ini dijalankan kerana berlakunya kejadian kemalangan kapal penumpang yang kerap berkaitan dengan penggunaan jaket keselamatan, yang dipercayai disebabkan oleh ketidakserasian antara jaket keselamatan dan kapal penumpang. Bagi menangani masalah ini, kajian ini telah membangunkan model penilaian keselamatan kapal penumpang pesisir (CPV) dalam perspektif keserasian dengan jaket keselamatan yang dikenali sebagai model Indeks Keserasian Jaket Keselamatan (LCI). Tujuan utama model LCI dibangunkan adalah untuk menilai keserasian antara jaket keselamatan dengan CPV. Model LCI telah dibangunkan berdasarkan gabungan pembolehubah-pembolehubah dari empat model keselamatan sebelumnya. Keserasian diperkenalkan sebagai pembolehubah baru dalam model ini. Pembangunan model LCI bermula dengan pemetaan pembolehubah dari kedua-dua model jaket keselamatan dan model keselamatan kapal penumpang yang gabungan. Pembolehubah-pembolehubah dipilih berdasarkan kriteria penyelidikan dan digunakan untuk membangunkan model (LCI). Model LCI berubah menjadi algoritma LCI Statik dan LCI Dinamik dengan menggunakan pendekatan analisa *Fault Tree*. Fungsi LCI Statik adalah menilai keserasian jaket keselamatan dengan CPV berdasarkan pelan kapal dan bilangan penumpang yang diluluskan, manakala fungsi LCI Dinamik adalah menilai keserasian yang sama semasa CPV beroperasi. Ketepatan model LCI telah disahkan dengan menggunakan kaedah regresi dan pengesahan lanjut telah buat melalui kajian kes dan analisis sensitiviti. Keputusan LCI Statik menunjukkan bahawa CPV jenis dek terbuka *Explorer 320* yang dilengkapi dengan jaket keselamatan apung kekal mempunyai keserasian yang lebih baik (2.79) berbanding CPV jenis tertutup dek *Duta Pangkor 3* dan *Bahagia No. 1* (1.79 dan 1.84 masing-masing). Model LCI telah digunakan untuk meningkatkan prestasi keselamatan *Bahagia No. 1*. Adalah didapati bahawa LCI Dinamik kapal tersebut boleh dipertingkatkan sebanyak 3.4% apabila bilangan penumpang dikurangkan daripada 57 kepada 55. Kesimpulannya, model LCI yang baru dibangunkan ini adalah penting untuk menilai dan meningkatkan keselamatan CPV.

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LIST OF ABBREVIATIONS

BSS	-	Boating Safety Scale
C	-	Comply
CATI	-	Computer Assisted Telephone Interviewing System
CLIA	-	Cruise Lines International Association, Inc.
FAA	-	Federal Administration of Aviation
FSA	-	Formal Safety Assessment
GA	-	General Arrangement
HELP		Heat Escape Lessening Position
IMO	-	International Maritime Organization.
ISO	-	International Organization for Standardization
LCI	-	Life Jacket Compatibility Index
LOA	-	Length Overall
LSA	-	International Life Saving Appliances Code
LSI	-	Life Saving Index
LWL	-	Waterline Length
MAIB	-	Marine Accident Investigation Branch
MCA	-	Marine and Coast Guard Agency UK
MSC	-	Maritime Safety Committee
MV	-	Motor Vessel
NC		Not Comply
NTSB	-	National Transport Safety Board
PFD	-	Personal Floatation Device
RBCM	-	Risk Based Compliance Assessment Model
RRN	-	Risk Ranking Number
SOLAS	-	International Convention on the Safety of Life at Sea 1974
SEE	-	Standard Error of Estimate
SPSS	-	Statistical Package for Social Science

TMI	-	Turning Moment Index
TSB	-	Transportation Safety Board of Canada
UK	-	United Kingdom
USA	-	United States of America
USCG	-	United States Coast Guard

LIST OF SYMBOLS

CO_2	-	Carbon Dioxide
I_E	-	Physical Effectiveness; the probability the PFD maintains the wearer in a position which permits continuous breathing.
I_R	-	Reliability; the probability that the PFD performs as designed.
I_W	-	Wearability; the probability that PFD is worn by the victim when he enters the water in a marine accident.
I_W	-	The probability that PFD is worn immediately prior to entering the water in an accident.
I_{AC}	-	The probability that the PFD is accessible to a boater but not worn initially upon entering the water in an accident (accessibility index)
P_D	-	The probability that the accident victim dons the PFD in the water
P_H	-	The probability that the accident victim holds or lies upon the PFD in the water
E_W	-	The probability that the PFD maintains or turns the wearer in the water to a position with a minimum required freeboard to the lower respiratory passage within a specified time limit (effectiveness when worn)
E_H	-	The probability that the PFD provides minimum required freeboard to the lower respiratory passage for a relaxed person holding or lying upon the device in the water (effectiveness when held)
R	-	The probability that a PFD will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended (reliability).
I_{AC}	-	Index of Accessibility
$F_{A_{MAX}}$	-	the greatest possible unadjusted accessibility factor score = 3.41
$F_{A_{MIN}}$	-	the smallest possible unadjusted accessibility factor score = -6.51

F_{Ao}	-	the adjusted accessibility factor score taken as the zero point for I_{Ac}
$NV5$	-	Proportion of Time Candidate PFD was Kept Accessible or Worn
$V70$	-	PFD worn by you + worn by another person (hour)
$V71$	-	PFD kept in open place (hour)
$V73$	-	Duration of outing (hour)
E_{WB}	-	The probability that the PFD turns the unconscious/relax wearer to a position with adequate freeboard.
E_F	-	The proportion of dummies tested representing females on which the PFD performed satisfactorily.
P_F	-	The proportion of the recreational boating accident population which is female. E_M and P_M are defined comparably for males.
I_A	-	Accessibility Compatibility Index
I_{SI}	-	Safety Instruction Compatibility Index
I_{SC}	-	Space Compatibility Index
I_{Ac}	-	Accessibility Compatibility Index
T_{Ac}	-	Duration of LJ kept accessible (hour)
T_D	-	Duration of LJ donned by passenger (hour)
T_J	-	Duration of journey (hour)
t_{ace}	-	time of life jacket end accessible
t_{acs}	-	time of life jacket start accessible
t_{de}	-	time of life jackets taken off by passengers
t_{ds}	-	time life jackets don by passengers
t_{je}	-	time of journey end
t_{js}	-	time of journey start
I_{SI}	-	Safety Instruction Compatibility Index
S_{Bo}	-	Safety Briefing Observed
S_{Br}	-	Safety Briefing Required
S_{Bo}	-	Safety Briefing Observed
I_{Ao}	-	Information on Emergency Alarm/Notification Observed
I_{Xo}	-	Information on Location of Emergency Exit Observed
I_{JLo}	-	Information on Location of Life Jacket Observed

I_{JDo}	-	Information on Life Jacket Donning Demonstration/Instruction Observed
I_{Eo}	-	Information on Location of Assembly Area or Embarkation Area Observed
I_{Po}	-	Information on Location of Safety Placards/ Instructional Poster por Life Jacket Observed
I_{JWo}	-	Information on When To Don Life Jacket Observed
A_i	-	Availability of each element
F_l	-	Effectiveness of each element
s_j	-	score of effectiveness of each element observed
w_k	-	weightage of each element
F_l''	-	denotes F_l in fuzzy form.
S_{Br}	-	Safety Briefing required
I_{Ar}	-	Information on emergency alarm/notification required
I_{Xr}	-	Information on location of emergency exit required
I_{JLr}	-	Information on location of life jacket required
I_{JDr}	-	Information on life jacket donning demonstration/instruction required
I_{Er}	-	Information on location of assembly area or embarkation area required
I_{Pr}	-	Information on location of safety placards/ instructional poster for life jacket required
I_{JWr}	-	Information on when to don life jackets required
I_{Scs}	-	Space Compatibility Index Static
S_A	-	Space available to don
S_{Ds}	-	Space required to don static
A_s	-	Area for each space
C_s	-	Possibility to don life jackets according to compatibility between type of space and type of life jacket
J_{bfe}	-	Inherently buoyant type life jacket not compatible to don in fully enclosed space
J_{bpe}	-	Inherently buoyant type life jacket not compatible to don in semi-

		enclosed space
J_{bo}	-	Inherently buoyant type life jacket compatible to don in open space
J_{ife}	-	Inflatable type life jacket compatible to don in an enclosed space
J_{ipe}	-	Inflatable type life jacket compatible to don in semi-enclosed space
J_{io}	-	Inflatable type life jacket compatible to don in open space
J_{cfe}	-	Combination of Inflatable and Inherently Buoyant life jacket in fully enclosed space
J_{cpe}	-	Combination of Inflatable and Inherently Buoyant life jacket in partially enclosed space
J_{co}	-	Combination of Inflatable and Inherently Buoyant life jacket in open space
N_i	-	Number of inflatable life jacket
N_b	-	Number of inherently buoyant life jacket
H_2	-	The inherently buoyant life jacket is not compatible with fully enclosed space of coastal passenger vessel
H_3	-	The inherently buoyant life jacket is compatible with open space of coastal passenger vessel
H_4	-	Inflatable life jacket is compatible with fully enclosed space of coastal passenger vessel
H_5	-	Inflatable life jacket is compatible with open space of coastal passenger vessel
H_6	-	The inherently buoyant life jacket is not compatible with partially-enclosed space of coastal passenger vessel
H_7	-	Inflatable life jacket is compatible with partially-enclosed space of coastal passenger vessel
S_{DS}	-	Space required to don static
A_D	-	Area required to don one life jacket
N_P	-	Approved maximum number of passengers
$LCID$	-	Life jacket Compatibility Index Dynamic
I_{AC}	-	Accessibility Index
I_{SI}	-	Safety Instruction Index
I_{SCD}	-	Space Compatibility Index Dynamic
I_{SCD}	-	Space Compatibility Index Dynamic

S_A	-	Space available to don
S_{D_D}	-	Space required to don dynamic
S_{D_D}	-	Space required to don dynamic
A_d	-	Area required to don one life jacket
N_{p_i}	-	Number of passenger dynamic

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter highlights the necessity of research on the development of the safety assessment model of coastal passenger vessel in the perspective of compatibility of life jackets with coastal passenger vessels. The problem statement and the research objective have been stated. The scope of the study and the significance of the research have also been itemized to show the research boundary and its strength and contribution respectively.

1.2 Background of Study

The safety of passenger vessels has been addressed by the establishment of the relevant national and international regulations since the aftermath of the RMS Titanic accident in 1912. One of the most important international safety regulations is the International Convention on the Safety of Life at Sea (SOLAS), 1974. Through the convention, continuous improvement on safety is introduced to passenger vessels in the aspect of design of passenger vessels, life-saving appliances, carriage of safety equipment and safety management system (IMO, 2009b).

Besides the introduction of safety regulations to improve the safety of passenger vessels, another way to improve the safety of passenger vessels is through the application of the assessment models. The examples of such models are Formal Safety Assessment for Cruise Ship introduced by Lois, *et al.* (2004), Boating Safety Scale introduced by Virk and Pikora (2011) and Crucial Safety Assessment Criteria for Passenger Ferry Services introduced by Lu and Tseng (2012).

One of the important safety aspects of passenger vessels is the carriage of life-saving appliances that contribute directly to the safety of passengers. The examples of the personal life-saving appliances are life jackets, life buoys, and immersion suits. Among the aforementioned, life jackets is the most important and carried for every person on board. The research on standards of life jackets has been initiated since 1950s until the present day (Ayub and Nejaim, 2003; Doll *et al.*, 1978b; Funkhouser and Fairlie, 1991; Gabb *et al.*, 1965; Hart, 1988; Herrmann, 1989; Lockhart *et al.*, 2005; Macdonald *et al.*, 2011; Macesker and Gareau, 1997; Macesker and White, 1992; Macintosh and Pask, 1957; Pask and Christie, 1962; Pask, 1961). The current enforced international standards for life jacket are International Life Saving Appliance Code under SOLAS 1974 and International Standard ISO 12402 (IMO, 1998, 2005, 2010; ISO, 2005). Similar with the passenger vessels, the improvement on safety of life jackets is through the introduction on assessment models. Examples of such research are Life-Saving Index model by Doll *et al.* (1978a, 1978b, 1978c) and Risk-Based Compliance Assessment Model by Ayub and Nejaim (2003).

Despite the continuous improvement on standards and the introduction of assessment models of passenger vessels and life jackets, accidents associated with the use of life jackets on board passenger vessels persist, although the number of cases is not significant. The examples of the two accidents highlighted in the following paragraph described the use of the inherently buoyant life jackets (fixed foam life jackets) in the enclosed space.

The first accident occurred in the year 1991 in Portsmouth, UK that caused loss of life of a nine year old female pupil that was wearing an inherently buoyant life jacket (MAIB, 2001). Upon capsizes, the pupil seated in the middle of the boat

was trapped under the up-turned boat. Her escape impeded by the buoyancy force of life jacket that pushed her towards the surface. Her chances of survival would be higher if she trapped in an air pocket under the up-turned boat. Her situation worsened by the further submerged of the up-turned boat due to the weight of some of the pupils that sat on top of the boat and some clung to the side.

The second accident occurred in 2007 in Scotland, UK that had caused loss of life of a 15-year-old female cadet who was using an inflatable life jacket (MAIB, 2008). Initially upon capsized, four cadets was under the up-turned boat. Three cadets who were not inflating their life jacket managed to swim-out. However, the fourth cadet who inflated her inflatable life jacket was unable to swim-out from the up-turned boat due to the buoyancy force of her life jacket that forced her towards the surface. Her chances of survival would be higher like the three cadets who survived, if she did not inflate her life jacket.

1.3 Problem Statement

This study considered the examples of accidents stated in section 1.2 caused by compatibility issue between the life jackets and passenger vessels (Groff and Ghadiali, 2003). Furthermore, Doll *et al.* (1978) and Groff and Ghadiali (2003) suggested life jackets should be compatible with the user activity. With respect to the records of accidents and suggestion, the existing assessment models of passenger vessel do not address the issue of safety with respect to compatibility of life jackets with passenger vessels (Lois *et al.*, 2004; Lu and Tseng, 2012; Virk and Pikora, 2011). Instead, the existing models only emphasize on the availability and carriage of life jackets without looking into the aspect of suitability and support for life jackets to don and operate by passengers on board the passenger vessels.

1.4 Objective

With respect to the accidents associated with the usage of life jackets, this study would address the issue by developing a safety assessment model for the coastal passenger vessels in the perspective of compatibility of life jackets with the coastal passenger vessels as the main research objective. The development of the new model is based on a combination of the assessment models of life jackets with assessment models of the passenger vessels. The new model would be able to rate the compatibility of life jackets with coastal passenger.

The goal can be achieved by meeting the following objectives:

- i. To develop a conceptual model to assess the compatibility of life jacket with passenger vessel by using variables in the previous models of life jackets and passenger vessels.
- ii. To develop algorithm to assess compatibility of life jacket with coastal passenger vessel.
- iii. To determine the algorithm is accurate and robust for application.

1.5 Scope of Study

The research limits its scope in the respective areas:

- i. Coastal passenger vessels involved in single or multiple leg voyages in the coastal area (within 12nm or 21.6km from the nearest coast) and not equipped with cabin facility for passengers to stay overnight and must comply with the national regulations.
- ii. Types of life jackets used this study are inherently buoyant (solid foam) and inflatable type, which comply with the national or international standard and available on board CPV in the required quantity.
- iii. Survey to verify the new variable is carried out among Marine Officers of Marine Department Malaysia, which is the leading regulatory body in Malaysia with respect to maritime safety and shipping in Malaysia.

- iv. The current model is developed based on a combination of variables from existing models of life jacket and models of passenger vessel which combines by compatibility as the new variable.
- v. The variables selected to develop the new model should be able to produce result by on site evaluation without the additional requirement to conduct laboratory tests.
- vi. The algorithm for the current model is developed by Fault Tree Analysis and Boolean Logic gate.
- vii. Validation of the current functional test and one-at-a-time sensitivity analysis.

1.6 Significance of Study

The significances of this research are as follows:

Contribution to the knowledge of the new model is the assessment of coastal passenger vessel in a new perspective and would complement the existing assessment models.

The new model would serve as an enforcement tool for maritime authority to regulate the safety operation of the commercial coastal passenger vessels.

The new model would serve as a tool for plan approval of coastal passenger vessel for maritime authority, which determines the maximum capacity of passengers in a new way or perspective.

The new model is a new contribution to the field of maritime safety.

The new model would improve the safety of lives at sea.

1.7 Theoretical Framework

The development of the new model is based on the combination of two types of safety assessment models, namely safety assessment model for life jackets and assessment model for passenger vessels, and using compatibility variable to combine these two types of models. The assessment models for life jackets are Life Saving Index (LSI) model developed by Doll *et al.* (1978b) and Risk-Based Compliance for Personal Floatation Device (Risk-Comp PFDs) developed by Ayub and Nejaim (2003). While the assessment models for the passenger vessels are Formal Safety Assessment (FSA) for Cruise Ship developed by Lois *et al.* (2004), Crucial Safety Assessment Criteria for Passenger Ferry Services by Lu and Tseng (2012) and Boating Safety Scale by Virk and Pikora (2011). The combination of the two types of the model is to develop a new model to assess the safety of coastal passenger vessels, in the perspective of compatibility of life jackets to access, don and operation in the coastal passenger vessel.

1.8 The Organisation of the Thesis

This thesis is divided into six chapters, namely Introduction as Chapter 1, Literature Review as Chapter 2, Research Methodology as Chapter 3, Results as Chapter 4, Discussion as Chapter 5 and Conclusion as chapter 6. This is followed by References and Appendices.

This thesis divided of six main chapters where each chapter will focus on the topics as follows:

Chapter 1 is an introduction to the research where it describes briefly the background of the research, the problem statement, the research objective and the significance of the research.

Chapter 2 of the report contains a literature review for the purpose of understanding the topic of the research in detail. This chapter contains related literature on life

jackets, passenger vessels, safety assessment models of life jackets, safety assessment models of passenger vessels, compatibility, accidents associated with life jackets and fuzzy.

Chapter 3 describes the methodology adopted for the research such the mapping of variables, statistics, Fault Tree analysis, Boolean logic gate, Triangular Fuzzy Number, and One-At-a-Time Sensitivity Analysis.

Chapter 4 shows the results of the research, namely model of Life Jacket Compatibility Index Static, Life Jacket Compatibility Index Dynamic, algorithm of Life Jacket Compatibility Index Static, algorithm of Life Jacket Compatibility Index Dynamic, results of verification and results of validation.

Chapter 5 discusses the results of chapter 4 in detail. The discussions focused on the achievement of the research objectives, the comparison of the current model with the existing models and the contribution of the current model in the field of maritime safety.

Chapter 6, which is the final chapter, presents the overall conclusion and recommendations for future research. This chapter highlights the findings and the contribution of the current research.

1.9 Summary

This chapter serves an introduction to this research, which mainly explains the background of the research, the problem statement, objectives of the research, scope of study, theoretical framework, and organisation of the whole thesis.

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